Inter-limb step asymmetry in closed and open skill sprint accelerations in soccer players

Abbreviated title: **Sprint acceleration inter-limb asymmetry**

Original research article

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Abstract:

Purpose: Inter-limb differences may have detrimental effects on sports performance. There is a need to understand the comparison of asymmetries between open and closed skill tasks. The study investigated inter-limb step asymmetry responses to closed and open skill acceleration sprint running tasks. Material and Methods: 3D motion analysis kinematic data of step characteristics were collected from 20 male soccer players (mean±SD: 21±1.9 years, 78.7±7.7 kg, 1.78±0.06 m) for bilaterally located lower-limb markers during the initial 20 m of closed and open skill acceleration sprint running trials. Step velocity, step length, step frequency, flight time, contact time and flight distance were calculated. In the closed skill condition, players were aware of the final sprint distance prior to initiation. In the open skill conditions, players were informed of the final sprint distance (20 or 40 m) immediately after initiating the run. Results: Players displayed significant (0.10 to 10.3 %, $p<0.05$) asymmetries in their step characteristics during closed skill acceleration sprint performances. Positive correlations (r=0.51 to 0.77, $p<0.05$) were evidenced between the asymmetry scores in the closed skill and in the open skill 20 m and 40 m conditions. Asymmetry scores were not found to be associated with sprint performance (r=-0.13 to 0.30, $p>0.05$), suggesting that asymmetry may be functional or dysfunctional. Conclusions: Skilled soccer players are able to regulate step characteristic asymmetries across closed and open skill tasks. Symmetry should not be assumed when assessing open and closed skill acceleration sprint performance in soccer players. Practitioners should be aware of these asymmetries when implementing programmes.

Key words: Soccer Training, Deterministic Models, Step Characteristics, Coaching, Biomechanics, Gait

INTRODUCTION

Inter-limb asymmetry compares the movement of one limb with respect to the other [1]. Evidence indicates that inter-limb differences measured across a range of tasks has a detrimental effect on physical and sport performance [2], and has potentially injurious consequences [3,4,5]. There has tended to be a stronger biomechanical research focus surrounding injury risk and occurrence when compared to physical or sports performance [2]. As a consequence of the increased interest in injury risk and occurrence, asymmetries of < 10% have been proposed as the target for when athletes are returning to sport [6], and that both athlete and non-athlete populations who exhibit greater inter-limb asymmetries in peak vertical countermovement jump force and the single leg hop test than 15% have been associated with increased injury incidence when compared to groups who score below this threshold [3,4,5]. However, there is currently a lack of research examining the effect of asymmetries on sports performance [2].

Despite a large number of studies that have focused on kinematic or kinetic asymmetry in submaximal running and walking gait [7,8,9,10], asymmetry has rarely been investigated in sprint running. Sprint running is a key determinant of performance within soccer and many other sports [11,12]. An explosive sprint was defined as the completion of sprint speed from standing, walking, jogging or running [13]. The majority of sprints in professional soccer are over short distances, where explosive sprints make up 23-30.5 % of these short sprints [13,14], which makes the ability to accelerate essential. According to Hunter et al.'s [15] deterministic models of sprint performance, the players velocity is determined by the step length, step frequency and their sub-determinants. Therefore, adaptations in lower level variables, such as joint angles, would have an affect on higher level variables (e.g. contact time, step length). Regardless of the importance of the ability to accelerate within soccer, and other field based sports, a current paucity of data examining acceleration sprint running asymmetries exists. Further research is required in a wide range of populations to more clearly determine if detrimental effects are shown in a variety of physical and sporting tasks to examine if thresholds exist that are related to performance decrements [2].

Current research has examined asymmetries during maximal sprinting tasks in youth athletes and reported weak relationships between the asymmetry variables and sprint velocity ($r = -0.24$ to 0.39; $p < 0.05$) [16]. With variables ranging from 2.3–12.6 %, the weak relationships reported by the respective study potentially indicate that sprint speed may not be detrimentally affected with the presence of inter-limb asymmetry as high as ~12 % in a healthy, youth population. However, Bishop et al. [2] highlighted that no specific details were provided on the sporting backgrounds of the participants. Meaning, any conclusions drawn from this study were not generalised to a homogenous, sporting sample of an equivalent or older age, such as adult soccer players. Therefore, further investigation into sport specific homogenous group is required.

Inter-limb kinetic and kinematic asymmetries have recently been assessed during the maximum velocity phase of a sprint in adult sprint-trained athletes [17] and found to be unrelated to mean sprint velocity. The respective study reported kinematic asymmetry values to be less than 10 %, step characteristics (step velocity, length and frequency) to be less than 2 % and kinetic asymmetries to range from 0.1–93.2 %. However, with a low sample size of 8, there is clarification required on the relationship between lower-limb asymmetries and sprint performance. Furthermore, closed skill protocols are typically used in studies investigating asymmetry, such as the studies of Exell et al. (17) and Meyers et al. (16), but for an application for sports that have an open skill element there is a need to understand the comparison of asymmetries between open and closed skill tasks.

In a large variety of competitive soccer situations, the performer is unable to pre-plan a movement as a reactive physical and cognitive response is necessary. The rate and extent of the biomechanical adaptation depends on the time required to physically and cognitively search for the appropriate movement pattern and the performer's experience within the particular constraints [18]. In soccer, and other field sports, the amendment of traditional closed-skill sprint running protocols to include unanticipated changes in task constraint may be justified in order to better reflect an open skill environment [19,20]. Currently, sprint step characteristic variables are investigated in closed skill environments. The existence of inter-limb asymmetry in acceleration sprint running and the extent to which inter-limb asymmetry is maintained or adjusted across sprint running tasks comprising differing constraints has yet to be fully elucidated. An explicit comparison of inter-limb asymmetry in open and closed skill tasks would potentially enable the development of closed skill screening methods that are representative of in-competition movement patterns in soccer. Closed skill screening protocols would help inform soccer players and coaches of potential imbalances and the effect of a player's asymmetry on performance.

The aim of this study was to empirically investigate inter-limb step asymmetry responses to closed and open skill acceleration sprint running tasks. Such information would provide insights into the degree of imbalance in step characteristics between limbs during acceleration sprint running in soccer players. It was hypothesised that significant inter-limb step asymmetries would be found in a number of the players, step characteristic asymmetries would be maintained across open and closed skill conditions, but that there would be no correlation between performance and step characteristic asymmetries.

MATERIAL AND METHODS

Subjects: Twenty semi-professional male soccer players (mean±standard deviation (SD): age 21±1.9 years, body mass 78.7±7.7 kg and stature 1.78±0.06 m) were recruited for the study. Recruited players were injury free, trained and played competitive soccer matches twice weekly, and further undertook two strength and conditioning sessions every week. The study was approved by the University's' Local Research Ethics Committee. Players were informed of the benefits and risks of the investigation prior to signing an institutionally approved informed consent document to participate in the study.

Procedures: The study was a randomised repeated measures design. Players were required to attend two data collection testing sessions, a minimum of 48 hours apart, in a National Indoor Athletics Centre. Players' whole-body mass and height were measured prior to the onset of the first data collection using laboratory weighing scales (Avery Berkel Ltd, model ED01) and a stadiometer (Holtain Ltd). During each session, players were required to perform five acceleration sprint running trials for a closed and two open skill protocols such that a total of ten player-specific trials were obtained for each condition across the two sessions. At the onset of the sprint and entering the 40 m sprint running zone a set of visual stimulating Smartspeed™ light gates (Fusion Sport, Grabba International Pty Ltd, London) were illuminated at two different open skill sprint running target distances (20 m: O20; 40 m: O40) from the start of the 40 m sprint running zone. Following triggering of the visual stimulating light gate, players were instructed to accelerate maximally to the respective sprint running target distance. For the closed skill condition (C20), the player was informed of the target distance (20 m) prior to the onset of the sprint running performance. The open and closed skill trials were performed in a random order and each player was given a minimum of five minutes rest period between each trial.

All sprint running performances were completed in a straight-line on a 110 m indoor athletics track (National Indoor Athletics Centre, Cardiff). For each trial, players were required to position themselves behind the start line in a standing position with the toes of their left foot immediately behind the start line, and the right foot placed comfortably behind. Players, who all wore rubber soled shoes, executed a 10 minute, self-guided warm-up and familiarisation with the sprint running protocols. Preceding the warm-up, two active Cartesian Optoelectronic Dynamic Anthropometer (CODA) motion, Charnwood Dynamics Ltd, Leicester, UK) markers were attached to the players using adhesive double-sided tape. The markers were connected to marker drive boxes and located on the toe (fifth metatarsal-phalangeal joint) of the right side and the toe (1st metatarsal head) of the left foot.

Four cx1 CODA motion scanners were horizontally aligned 3.0 m perpendicular to the plane of motion at 2.5 m, 7.5 m, 12.5 m and 17.5 m locations from the onset of the 20 m sprint running zone. The respective scanners were used to capture (sample rate: 200 Hz) three-dimensional coordinate data of the active toe markers over the initial 20 m of each sprint condition. The CODA motion system was manually triggered prior to the initiation of the player's sprint running performance.

Data Processing & Analysis: The captured three-dimensional coordinate data of each active marker were reduced to two-dimensions (z-vertical, y-anterior-posterior) and processed using a customised MATLAB program (2008b, The Mathworks, USA). Prior to further analysis, the respective raw coordinate data for the entire capture volume were filtered using a fourth-order, low pass Butterworth filter with a cut-off frequency of 12 Hz, which was determined using a residual analysis.

Individual steps were defined within each running trial using consecutive foot-ground touchdown events. For each step during the initial 20 m zone, touchdown (initiation of the stance phase) and toe-off (end of stance phase) were determined using the time of the peak filtered z-acceleration [21] of the active toe markers and a minimum z-displacement. Forefoot striking was assumed for all conditions and step cycles. The method of calculating step characteristics was based on Salo et al. [22]. A step was subsequently defined from the instant of touchdown (initial) of one foot, to the instant of the following touchdown (final) event for the contralateral foot [22]. The stance phase was defined as the instant of touchdown of one foot to the instant of the subsequent toe-off event for the same foot. Three outcome measures were calculated for all steps from the trials: Step length (SL) was defined as the y-displacement of the active toe marker between the respective left and right foot touchdown events; Step frequency (SF) was defined as the reciprocal of the duration between the initial and final touchdown events while step velocity (SV) was calculated as the product of SL and SF. Sub-component measures, which were considered to mechanically underpin the outcome measures [15] were also obtained from the trials. The measures included the flight distance (FD), which was defined as the y-displacement of the active toe marker from toe-off of one foot to the touchdown of the contralateral foot; flight time (FT), which was defined as the duration between the toe-off of one toe to the touchdown of the contralateral toe and contact time (CT), which was determined as the duration between the touchdown and initiation of stance phase to the toe-off and consequent ending of the stance phase for the same foot.

The mean and standard deviation (SD) of the step characteristics for both the right and left side were calculated for each trial and then data were pooled for each condition for every participant. The performance outcome velocity (VEL) was calculated as the mean of the left and right side step velocity for a trial, and the mean ±SD was calculated for each participant in the closed skill 20 m condition. Asymmetry scores were subsequently calculated for every step characteristic for each participant (n=20 participants) in the separate conditions using the method of Zifchock et al. [23].

Statistical Analysis: The performance outcome velocity, step characteristics, sub-component measures and asymmetry scores for the group and individual were tested for homogeneity of variance, sphericity and normality using a Levene’s test, a Mauchly’s test and a Kolmogorov-Smirnov test. All players had a number of variables that were not normally distributed so non-parametric statistics were used for further analysis. Differences between right and left side step characteristics for every participant in the C20 condition were quantified using a Wilcoxon signed-rank test (SPSS version 20.0, Chicago, USA), with the level of significance set at an alpha level of 0.05. To assess differences in asymmetry scores between conditions at the group level, a repeated measures analysis of variance (RM ANOVA) with a Bonferroni post-hoc test for repeated measures was conducted. The level of significance was set at an alpha level of 0.01. To ascertain a large effect with a statistical power of 85 % a sample size of 20 was deemed appropriate (GPower 3.1.9.4, Universitat Kiel, Germany).

Spearman's correlation coefficients were calculated to investigate pairwise correlations between step characteristic asymmetry scores in each condition at the group level. Asymmetry scores of the step characteristics in the C20 condition were correlated with performance outcome (VEL) to investigate the role of asymmetry in acceleration sprint performance. The level of significance was tested at an alpha level of 0.05.

RESULTS

Table 1 provides the asymmetry scores for step characteristic variables in the closed skill 20 m (C20) condition for every participant. Sixteen of the twenty participants displayed significant ($p < 0.05$) asymmetry in one or more of the step characteristics variables. No significant differences ($p > 0.01$) were found between conditions for the asymmetry scores in any of the step characteristic variables (Table 2.). The variable with the lowest asymmetry score was the CT (C20:1.00±0.96 %; O20:1.10±0.93 %; O40: 1.04±0.98 %), whereas the FT (C20: 4.23±3.00 %; O20: 5.81±2.81%; O40: 4.98±2.55 %) was observed to have the largest asymmetry scores.

INSERT TABLE 1 & 2 HERE

Table 3 describes the pairwise correlations between condition responses for each of the step characteristic asymmetry variables. Each asymmetry score was either moderately or strongly correlated between conditions. For the SV asymmetry score, positive moderate to strong correlations were observed between the closed skill 20 m (C20) condition, and the open skill 20 m (O20) ($r = 0.77$, $p<0.05$) and open skill 40 m (O40) ($r = 0.51$, $p<0.05$) conditions. The SF asymmetry scores were strongly correlated between the closed skill 20 m (C20) condition, and the open skill 20 m (O20) ($r = 0.81$, $p<0.05$) and open skill 40 m (O40) ($r = 0.86$, $p<0.05$) conditions. The SL asymmetry scores were moderately correlated between the closed skill 20 m (C20) condition, and the open skill 20 m (O20) ($r = 0.60$, $p<0.05$) and open skill 40 m (O40) ($r = 0.51$, $p<0.05$) conditions. Step characteristic asymmetry scores were not significantly correlated with performance outcome (VEL).

INSERT TABLE 3 HERE

DISCUSSION

The aim of this study was to empirically investigate inter-limb step asymmetry responses to closed and open skill acceleration sprint running tasks. In order to examine if asymmetries are transferred across open and closed skill acceleration sprint running tasks and to elucidate the effect of asymmetry on acceleration sprint performance. The main findings were that the majority of soccer players in the study displayed asymmetry in their step characteristics, and these asymmetries were maintained across closed and open skill acceleration sprint protocols. However, asymmetry in step characteristics were not associated with performance outcome.

Investigations are required into asymmetrical movement in a wide range of populations [23] to more clearly determine if detrimental effects are shown in sporting tasks, and to examine if thresholds exist that are related to performance decrements [2]. The players in the current study displayed low level of asymmetry across each of the step characteristics measured (1.00±0.96 % to 4.23±3.00 %). Sixteen of the twenty players displayed significant ($p<0.05$) asymmetries in one or all of the step characteristics measured. Ten players displayed significant asymmetries in the step velocity, indicating a consistently higher velocity in one leg than the other. According to deterministic models of sprint performance (e.g. 15), the contribution of lower level step subcomponent asymmetry to overall step velocity asymmetry can be traced to the flight time, where fourteen players displayed significant asymmetries. However, only four players had significant symmetries in the contact time, suggesting that flight time is the subcomponent that may be most susceptible to asymmetrical differences in soccer sprint acceleration. The inter-player differences in asymmetries reinforce the importance of individual analyses [22,24]. These findings are important to practitioners as it highlights that there are often significant asymmetries present in soccer player's acceleration sprint running step characteristics and that individuals employ different mechanisms to ensure performance is regulated.

It has been recently postulated that there may be relationships between a variety of asymmetry metrics, including step characteristics and sprint velocity [16], but that supporting literature is sparse. There is value in understanding whether asymmetry in performance is detrimental as it requires diverse conditioning responses to address limb dominance. The findings of the respective study supported the hypothesis that there would be no correlation between performance and step characteristic asymmetries. No relationships between velocity (VEL) and step characteristics asymmetry scores were observed. These findings are not unique to soccer players performing an acceleration sprint, as recent research investigating asymmetry in adult trained athletes during the maximum sprint phase [17] highlighted a lack of any relationship between step characteristics and performance outcome. The inconsistency between asymmetry and performance in acceleration sprint running suggested that asymmetry may be both functional and dysfunctional for different athletes. Exell et al. [17] argued that in performers that have an imbalance in strength or mobility around specific joints, asymmetry may be explained through the concepts of self-organisation [25] and be a functional requirement to optimise performance. On the other hand, for other soccer players, asymmetry may be seen as noise and indicate that one side of the body is not performing as optimally as the other, requiring technique adjustment. Another explanation for no relationship between velocity (VEL) and step characteristic asymmetry could be as a result of the low values of asymmetry present at the individual level (0.10 to 10.3 %). The majority of variables at the group and individual level were below the 10-15 % threshold that have been proposed as the target for when athletes are returning to sport [6], and reduced injury prevalence [3,4,5]. Current understanding has not yet extended thresholds to performance, however our results suggest that no performance decrements exist in lower-limb step characteristic asymmetries below the threshold of 10-15 %. Therefore, it is important for practitioners to understand that lower limb asymmetry may be ever present during soccer acceleration sprint performance but that it may only be detrimental to specific individuals.

The second hypothesis predicted that when compared to a planned (closed skill) sprint running task, a reactive (open skill) task would be consistent in the quantity of asymmetry in step characteristics and subcomponents across the different tasks. Traditional protocols, utilised to assess and develop field sport performance have been criticised due to the lack of unpredictability in the movement tasks employed [26]. This hypothesis was found to be true as there were no significant differences ($p>0.01$) found in asymmetry scores across condition, as well as moderate to strong correlations ($r=0.41$ to 0.84) between asymmetry variables in each condition. Asymmetry in acceleration sprint running may therefore transfer across different open skill tasks. These findings support the concept of a strong self-organisation by the soccer players in adapting to unanticipated changes in task constraint [25]. Asymmetry in step characteristics and their subcomponents may therefore be a learned response that is stable irrespective of task constraint in skilled performers. Such understanding may allow for the creation and implementation of performance screening tests quantifying asymmetry in a closed skill task that is still applicable to movements in an open skill competition environment.

It is important to mention that the approach used in the current study of assessing the step characteristic asymmetry during an acceleration sprint run can provide quick and accessible information over a large 20 m capture volume within a field setting. The information gathered from such protocols can help inform the practitioner of underlying asymmetries in a performer, and through an individual level analysis determine whether the asymmetries are functional or dysfunctional. Further study is required that examines the joint kinematics and kinetics during these acceleration sprint runs to further understand the mechanisms that underpin, according to deterministic models of sprint performance (e.g. [15]), the asymmetry found at top level step characteristics and their subcomponents. A limitation of the current study is that we averaged all the steps over the 20 m sprint performance, which may have limited the sensitivity of detecting asymmetries. Investigation into the different phases of a sprint performance (e.g. early, mid, and late acceleration subphases [27]) may provide more sensitive information on the nature of lower-limb asymmetries and their relationship with performance.

From a data collection perspective, symmetry should not be assumed when assessing top level deterministic parameters of acceleration sprint performance in soccer players. Where only a unilateral 2-dimentional analysis is possible, caution should be used when inferring from results, and practitioners should be aware of potential differences in the limb not analysed. The results of our study suggest that lower-limb step characteristics asymmetries during acceleration sprint performances are very individual and that asymmetries may be functional or dysfunctional to performance depending on the individual. Therefore, practitioners should assess sprint performance asymmetries at the individual level and in line with current understanding [2] use bilateral and unilateral strength, balance and core training to reduce lower-limb asymmetries.

CONCLUSION

In conclusion this research highlighted that soccer players display significant asymmetries in their step characteristics during acceleration sprint performances in both open and closed skill tasks. No relationships between step velocity and step characteristics asymmetry scores were observed, providing evidence that asymmetry may be both functional and dysfunctional for different athletes. Finally, skilled soccer players are able to regulate step performance asymmetries across closed and open skill tasks, which provides a basis for the development of closed skill asymmetry performance screening protocols in soccer. Future research should examine whether these step characteristic asymmetries are present in the underlying mechanics of joint kinematics and kinetics.

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Table 1. Asymmetry scores (%) for step characteristic variables in the closed skill 20 m (C20) condition.

Player	SV	SL	SF	FT	CT	FD
1	0.23	0.63*	0.41*	0.86*	0.00	0.65*
2	0.12	2.23	1.91	4.03*	0.23	2.42
3	0.68	0.79	0.02	0.37	1.4	0.83
4	0.19	0.77	0.91	2.61	0.81	0.94
5	0.10	2.92*	2.99*	5.65*	0.27	2.82*
6	2.21*	1.93	4.08*	7.31*	1.31	1.83
7	1.26*	2.04*	3.38*	6.10*	1.3	2.40
8	0.75	1.01*	1.76	1.46	1.43	1.09
9	1.52*	0.32	1.22*	2.26*	0.24	0.22
10	0.21	0.34	0.28	0.00	0.00	0.24
11	0.86*	3.29*	2.22*	5.32*	0.25	3.83*
12	2.96*	1.84*	4.56*	10.3*	0.24	2.38*
13	1.22*	0.02	1.16	3.38*	0.77	0.11
14	0.97	1.83*	2.73*	6.77*	0.45	2.41*
15	1.35*	1.12	2.13	4.28	0.53	1.14
16	2.18*	1.12*	3.41*	5.29*	1.57*	1.43*
17	2.73*	3.69*	6.44*	9.88*	3.14*	3.58*
18	0.05	1.26*	1.05*	4.2*	2.00*	1.42*
19	3.26*	0.98	4.37*	5.49*	3.38*	0.96
20	0.13	0.33	0.36	0.00	0.75	0.29

*Significant ($p<0.05$) difference between right and left values (n=10). Step velocity (SV), step length (SL), step frequency (SF), flight time (FT), contact time (CT), flight distance (FD).

Table 2. Mean ± Standard deviation of group (n=20) step characteristics asymmetry scores (%) in the closed skill 20 m (C20), open skill 20 m (O20) and open skill 40 m (O40) conditions.

Variable	C20	O20	O40
SV	1.15±1.03	1.13±1.03	1.34±0.80
SL	1.42±1.03	2.27±1.17	1.62±1.11
SF	2.27±1.17	2.70±1.66	2.34±1.67
FT	4.23±3.00	5.81±2.81	4.98±2.55
CT	1.00±0.96	1.10±0.93	1.04±0.98
FD	1.55±1.11	2.22±1.16	1.77±1.08

There were no significant ($p<0.01$) differences between conditions. Step velocity (SV), step length (SL), step frequency (SF), flight time (FT), contact time (CT), flight distance (FD).

Table 3. Spearman's correlations (r) of the group (n=20) step characteristic asymmetry scores between the closed skill 20 m condition (C20), the open skill 20 m (O20) and 40 m (O40) conditions, and the closed skill 20 m performance outcome step velocity (VEL).

C20	O20	O40	VEL
SV	0.77*	0.51*	
SL	0.60*	0.51*	-0.13
SF	0.81*	0.86*	0.30
FT	0.71*	0.78*	0.22
CT	0.41*	0.60*	0.10
FD	0.60*	0.59*	-0.06

*Significant ($p<0.05$) correlation with C20 condition.